REMOTE SENSING CENTRE

LANDSAT—A TOOL FOR MAPPING FUEL TYPES IN THE BOREAL FOREST OF MANITOBA: A PILOT STUDY

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Landsat - a Tool for Mapping Fuel Types in the Boreal Forest of Manitoba: a Pilot Study

by

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ABSTRACT

Forest lands are a major contributor to the economic and social development of Manitoba. Demand for forest resources are expanding, and therefore, the need for intensive forest management is increasing.

Fire management is an essential component in the administration of forest land. Wildfire managers require specific information to accurately predict fire behavior. One important factor affecting fire spread and intensity is the type of vegetation or fuel type. Consequently, maps which display the location, areal extent and type of fuel complexes are helpful in assessing probable wildfire behaviour.

The objective of this study was to demonstrate the feasibility of Landsat MSS digital data for fuel type mapping in the Boreal Forest of Manitoba. The study area was located in northwestern Manitoba between latitude 54 and 55 degrees north, and between longitude 100 and 102 degrees west.

Techniques of image classification and enhancements were evaluated. A DIPIX Applied Resource Image Exploitation System (ARIES-II) image analysis system was used to do computer analysis on four Digital Image Correction System (DICS) scenes dated June 26th, 1981. One map was produced for each DICS scene.

Confusion matrices were generated to determine classification results. The Lowland region had an overall classification accuracy of 70 percent. The majority of the

misclassification was attributed to difficulties in separating jack pine (Pinus banksiana) from other softwoods. On the Precambrian Shield, softwoods were combined resulting in an overall accuracy of 80 percent for the region. An Applicon inkjet plotter was used to produce colour thematic maps of the themes generated by the classification. The maps display the location and distribution of the main vegetation/ cover types and the associated Canadian Forest Fire Behavior Prediction (FBP) System fuel types.

Digital image enhancements were produced at approximately 1:150 000 scale. Principle component enhancements were generated using a process developed by fire management staff at the Petawawa National Forestry Institute, Canadian Forestry Service.

Enhancements were compared to the thematic maps and there was general agreement between themes on the two sets of data. However, many of the cover types on the enhancements had similar colours.

The project has demonstrated that Landsat MSS digital data can be used for fuel type mapping in Manitoba. The Manitoba Department of Natural Resources, Fire Management and Communications Section will integrate the study information into the fire management program for the 1984 fire season and expand forest fuel mapping to other areas of the province.

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1.0 INTRODUCTION

The Department of Natural Resources, Government of Manitoba and the Department of Energy, Mines and Resources, Government of Canada entered into a joint remote sensing Technology Enhancement Program (TEP) in 1982 by a Memorandum of Understanding (Appendix I).

The purpose of the program was to demonstrate the value of remote sensing technology for the management of Manitoba's natural resources. It involved federal government agencies as developers and provincial agencies as adopters of this technology. Within the program a demonstration project was conducted with the Fire Management Section, Regional Services Branch, Department of Natural Resources.

1.1 Background

Forest lands of Manitoba represent more than 60 percent of the total area of the province. This natural resource is a major contributor to the economic and social development of Manitoba. Products such as lumber, pulp and paper, and chemicals generate millions of dollars each year. Increased leisure time has broadened the utilization of forest land for recreational purposes. The forest also regulates hydrological resources, prevents degradation of soils, modifies the climate and provides shelter for wildlife.

Demand for the forest land resources is expanding and the need for intensive forest management is increasing. One aspect of forest management involves the protection of the resource to minimize losses such as those resulting from wildfires which spread over thousands of hectares of forest land every year. During the 1981 fire season more than 376 220 hectares (929,263 acres) of forest land were burned. Suppression expenditures exceeded seven million dollars during this period (Department of Natural Resources 1981/82).

Fire management is an integral part of the administration of forest land resources. In this regard wildfire managers require specific information in order to predict fire behavior and in turn make decisions with respect to fire control and suppression activities. One important factor affecting wildland fire spread and intensity is the type of vegetation or fuel type. A beneficial tool in evaluating potential fire behavior are fuel type maps.

Satellite data have been used successfully to assist in fire management activities in several regions of North America. Rabii (1980) was able to identify thirteen fuel type classes using Landsat 2 data in Crater Lake National Park, Oregon. Salazar (1982) found that the use of remote sensing techniques could provide basic pre-attack fuel type maps that were reliable and easily updated. Cosentino and Estes (1982) identified twelve fuel types in California with an overall classification accuracy of 89.9 percent. An important component of their project was to register resampled 50 metre Landsat data precisely to topographic

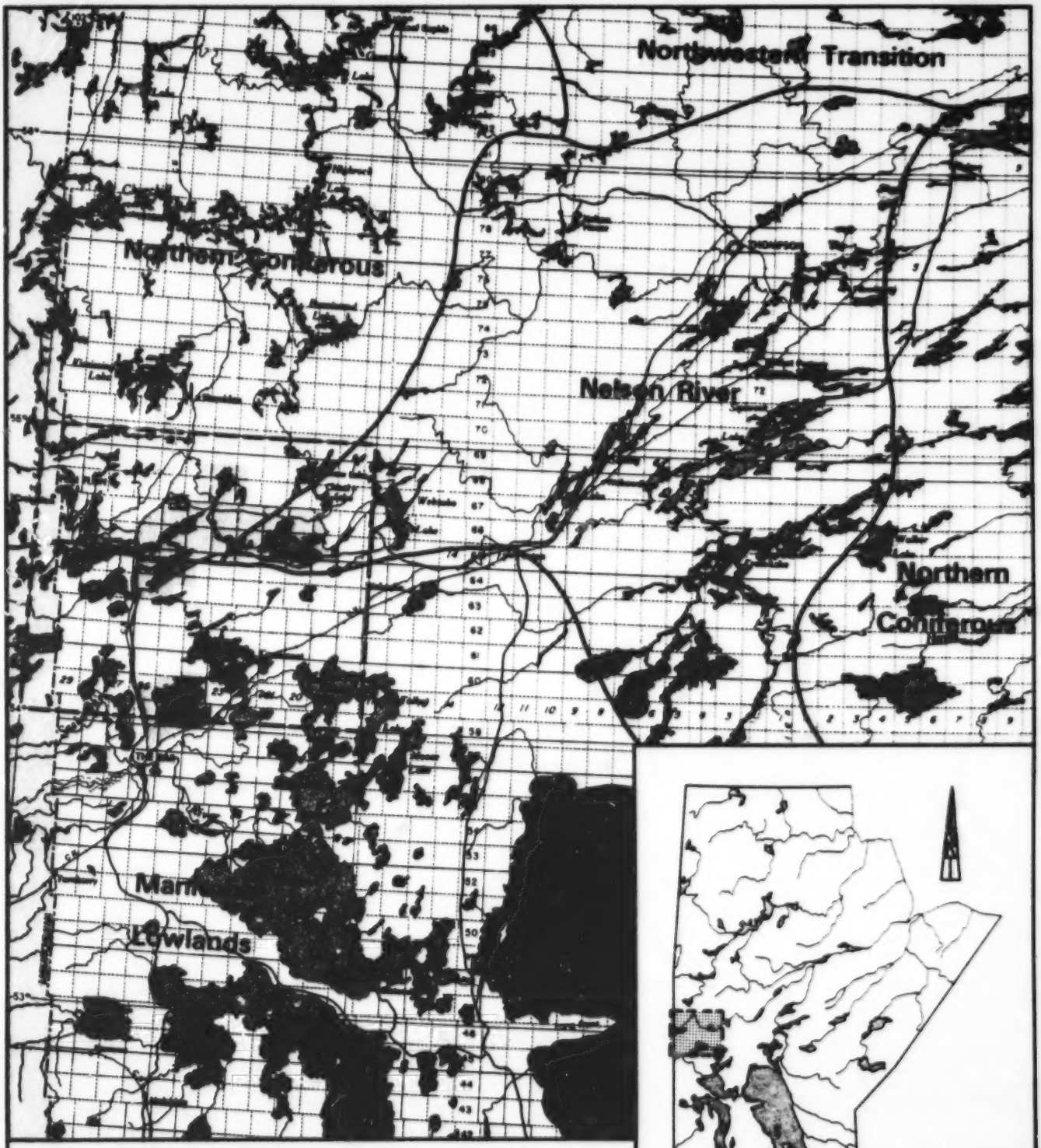
maps. Kourtz and Scott (1978) examined the capabilities of digital enhancement techniques for fuel type mapping and were able to show forest vegetation classified into broad categories that would exhibit similar fire behavior. Cosentino et al (1981) developed maps of vegetation characteristics which influence fire spread rate and other fire behavior characteristics.

1.2 Objective

The objective of this study was to demonstrate the feasibility of using Landsat MSS digital data as a tool for fuel type mapping in the Boreal Forest of Manitoba. Specifically, techniques of image classification and enhancements were evaluated.

2.0 THE STUDY AREA

The study area in northwestern Manitoba was contained within a single Landsat frame and one 1:250 000 National Topographic Series (NTS) map sheet (63K). It was located between latitude 54 and 55 north, and between longitude 100 and 102 west (Figure 1). Approximately ninety percent of the study area is in Manitoba and the remainder is in Saskatchewan.



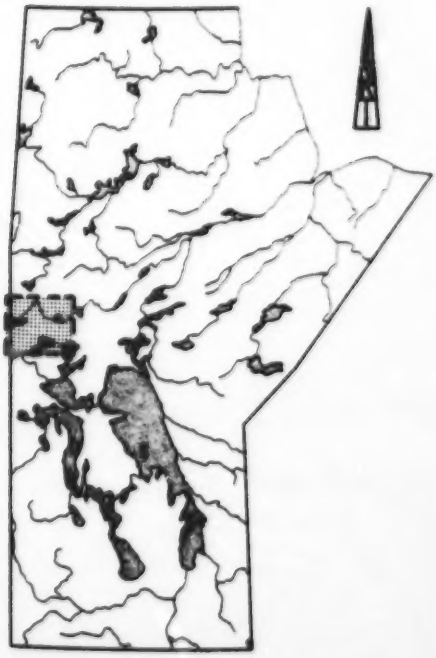
FOREST SECTIONS OF THE BOREAL FOREST

STUDY AREA

Scale 1:2 000 000

Source : Rowe 1972

Figure 1



Key Map

Geology

The geology of the area is divided between northern Precambrian Shield and Paleozoic Lowlands. The northern Precambrian Shield is comprised of volcanic, gneissic, quartzite and granite bedrock. Surficial geology is bedrock controlled with a thin layer of drift, numerous rock outcrops, ridges, knolls and depressions, and a local relief of less than 20 metres. Depressions are occupied by lakes, fens and bogs (muskeg).

The southern half of the study area was in the Paleozoic Lowlands with bedrock comprised of limestone and sandstone. The bedrock surface is flatter and smoother than the area to the north having a gentle relief of less than 10 metres. The drift is much thicker than in the Precambrian Shield but much of the land area is flat and poorly drained.

Vegetation and Soils

The study area fell within the Boreal Forest region and includes three forest sections as described by Rowe (1972) Figure 1. The Northern Coniferous section was located on the Precambrian Shield. Forest cover on the thin-soiled uplands was predominately black spruce (*Picea mariana*) with associated jack pine(*Pinus banksiana*). Poorly drained lowland areas were mainly black spruce with associated tamarack (*Larix laricina*). Local areas with favorable soil and micro-climate were comprised of

mixed stands of white spruce (Picea glauca), balsam fir (Abies balsamea), trembling aspen (Populus tremuloides) and balsam poplar (Populus balsamifera).

Manitoba Lowlands forest section was found on the Paleozoic Lowlands. The flat, poorly-drained land area was composed of patches of black spruce and tamarack intermixed with fens, swamps and muskeg. Low ridges throughout this section were forested with jack pine and trembling aspen. Sites bordering rivers and streams were usually better drained and could support stands of white spruce, balsam fir, trembling aspen and balsam poplar. The soils were generally lacustrine clays with peat on poorly drained sites.

The Nelson River forest section on the northeast corner of the study area is part Precambrian Shield. Black spruce was the dominant forest cover on both upland and lowland sites. On better drained areas, good stands of white spruce, balsam fir, balsam poplar and trembling aspen were found. Tamarack was commonly associated with black spruce on the poorly drained sites. High incidence of fire in this section has resulted in large areas of young trembling aspen and jack pine or grassy scrub on rock barrens. The section was characterized by fairly level lacustrine clays and sands with peat on poorly drained areas.

3.0 METHODS

3.1 Data Acquisition

Landsat microfiche files at the Manitoba Remote Sensing Centre (MRSC) were searched for the most suitable multispectral scanner (MSS) images (Table 1). The criteria for selection were: cloud free images (<5 percent) that coincided with maximum phenological activity for northern (boreal) conifer forests.

The product format chosen was Digital Image Correction System (DICS) images. This geometrically corrected format was easily registered to NTS map sheets and ground reference data.

Table 1: Four DICS Images for Project Area

Frame Number	Date of Images	DICS MAP Sheet #	NTS MAP Sheet #
22347-17003	26 June 1981	63K05	63K/SW
22347-17003	26 June 1981	63K07	63K/SE
22347-17003	26 June 1981	63K13	63K/NW
22347-17003	26 June 1981	63K15	63K/NE

3.2 Reference Data

Reference data consisted of aerial photographs, forest inventory maps and National Topographic Series maps.

Panchromatic aerial photography dated 1966-67 and 1982 were used. The 1982 photographs were taken during the summer at a scale of 1:15 840 for Forest Inventory purposes and provided coverage of the bottom two-thirds of the study area. Where 1982

coverage was not available the 1966-67 photography (1:15 840) was used. Forest Inventory maps compiled at 1:15 840 were obtained at a reduced scale of 1:50 000 along with their corresponding data sheets. The maps were generalized by grouping similar forest cover types, to allow for an easier comparison with satellite data. National Topographic Series maps provided geo-reference information for analyzing Landsat data.

3.3 Fuel Type Classification

Fuel types related to land cover/land use in the Boreal Forest along with weather and topographic parameters are considered to be the primary factors influencing fire behavior. Once ignited, there must be sufficient fuel of appropriate size and arrangement and sufficient dryness to support spreading combustion (Van Wagner 1983).

Northern forest fuels were mainly of four kinds; a simple litter layer of dead foliage; second, deep organic layers; third, fallen and standing dead trees and fourth, the major fuel category which is the live foliage.

Fuels change in terms of moisture content as determined by the fuel moisture codes of the Canadian Forest Fire Weather Index System (Canadian Forestry Service 1984). These changes in moisture content along with fuel type, wind velocity and topography (e.g., % ground slope) are the chief determinants of fire behavior.

Therefore, the use of fuel type maps can prove useful to the fire manager in predicting fire behavior when used in conjunction with the Canadian Forest Fire Behavior Prediction (FBP) System. (Alexander, Lawson, Stocks and VanWagner, 1984)

Fire Management and Communications section required eight fuel types to be mapped. Landsat digital data were used to identify land cover/land use types which were then matched to corresponding FBP System fuel types where possible (Table 2).

In addition to fuel types, rock outcrops and water bodies which represent natural barriers to fire spread, were also identified and classified for mapping.

TABLE 2. LANDSAT COVER TYPES AND THE CORRESPONDING CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM FUEL TYPES

LANDSAT Cover Type	FBP SYSTEM FUEL TYPE(S)[1] Identifier	Descriptive Name	FBP SYSTEM FUEL TYPE CHARACTERISTICS[1] (Abridged)
1. Jack Pine	C-4	Immature Jack Pine	- occurs on regenerated burn sites greater than 20 years old. - dense stands; continuous vertical crown fuel; heavy dead and down wood fuel; continuous needle litter. - fully stock stands; sparse conifer understorey; sparse wood fuels; tree crowns separated from ground; forest floor continuous feather moss.
	C-3	Mature Jack Pine	
2. Softwoods	C-2	Boreal Spruce	- moderately well-stocked spruce stands on both upland and lowland sites; continuous shrub; low to moderate down woody fuels; tree crowns extend nearly to the ground; continuous feather moss.
3. Hardwoods	D-1	Leafless Aspen	- moderately well-stocked aspen stands; leafless (i.e. spring & fall); medium to tall shrubs and herb layer; absent conifer understorey; sparse dead and down woody fuels; continuous leaf litter.
4. Mixedwoods	M-1	Leafless - Spring & Fall	- moderately well-stocked mixed stands of deciduous and conifers; scattered to moderate conifer understorey; conifer crowns extend nearly to the ground; - low to moderate dead and down woody fuels; moderate shrub and continuous herb layer; discontinuous feather moss and needle litter in conifers.
	M-2	Summer	
5. Cutovers	S-1	Jack Pine Slash	- difference slash types cannot be separated on LANDSAT, therefore all cutovers were assigned to the most hazardous slash fuel type in the FBP System. - continuous slash from clearcut logging; mature jack pine; high foliage retention; absent to sparse shrub and herb cover; continuous feather moss and needle litter.
6. Marsh	O-1	Grass	- continuous grass and grasslike cover, with no more than occasional trees or shrubs; continuous dead grass litter - during the summer season in Manitoba, this fuel type is affected by the extent of standing water.
7. Recent Burns		N/A	- there is no category in the FBP System for burns less than 5 years old. Flammability varies according to the degree of fuel consumption.
8. Muskeg		N/A	- scattered black spruce & tamarack stands on lowland sites; continuous shrub e.g. labrador tea, common; tree crowns often extend to ground; deep sphagnum moss; deep compact organic matter; localized pools of stand water Note: These lowland forests require a prolonged drought before they are rendered susceptible to fire spread.

[1] According to Alexander, Lawson, Stocks, and Van Wagner (1984)

3.4 Data Analysis

Digital image analysis was conducted at the Manitoba Remote Sensing Centre with the Dipix Systems Ltd. ARIES II (Applied Resources Image Exploitation System). The ARIES II is capable of displaying, analyzing and processing not only Landsat multi-spectral scanner (MSS) images but other forms of digital data in raster format.

Two digital analysis techniques: a fuel type thematic classification versus a digital enhanced image for human interpretation of fuel types were evaluated to determine which would be best for fire management purposes.

3.4.1 Classification Methodology

Landsat digital classification was the first method applied and it involved a computer process which grouped picture elements (pixels) with similar spectral characteristics. This technique, referred to as "spectral pattern recognition", required each cover type of interest to be spectrally similar within the project area. In addition, each cover type had to be spectrally separable from the other cover types.

A supervised classification method was employed and training areas were selected with the aid of 1:15 840 panchromatic aerial photography, forest inventory and topographic maps (Figure 2).

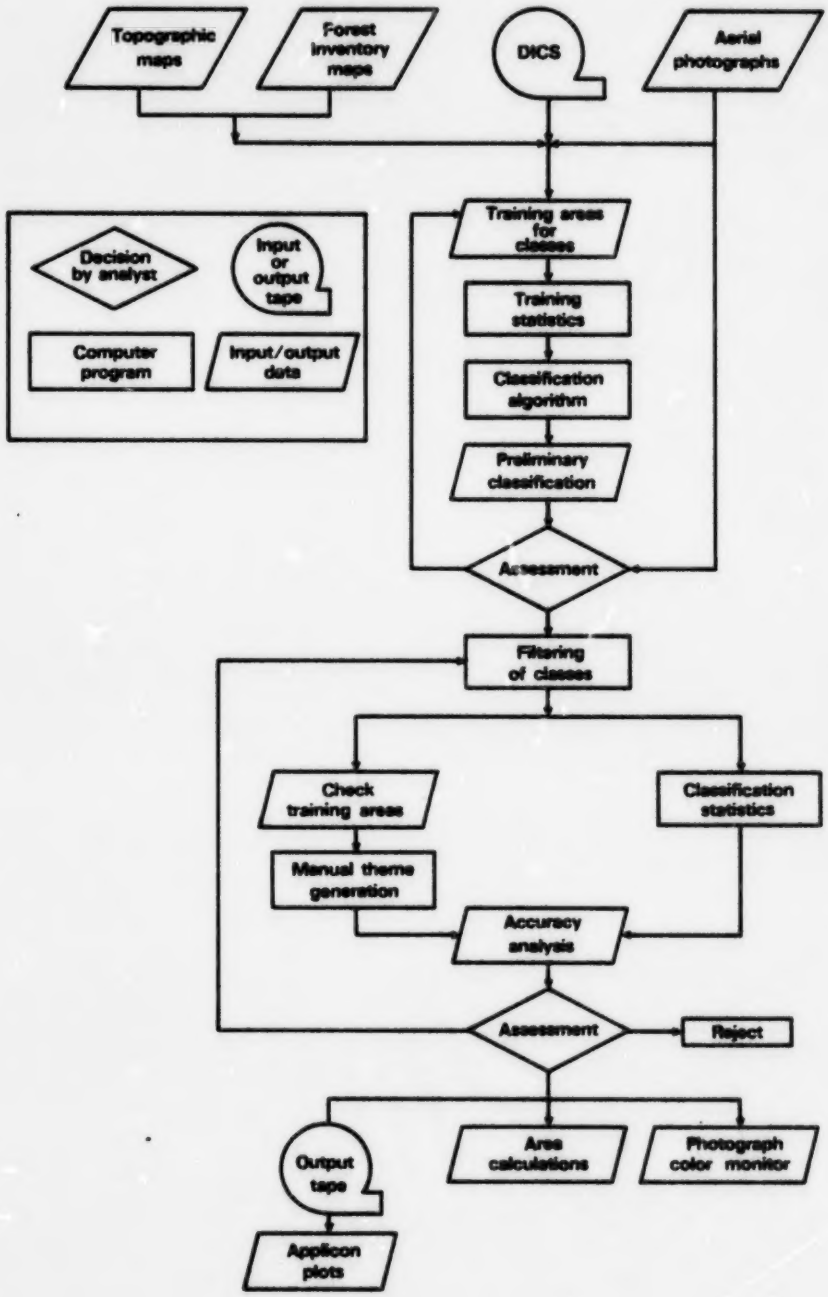


FIGURE 2: Flow chart of image analysis procedures followed on the ARIES system.

Training areas refer to groups of pixels known to represent the spectral characteristics of a known cover type. Areas were selected by using the ARIES-II "HIPAD" graphics tablet with its cursor. Boundaries were drawn around representative pixels displayed on the colour T.V. monitor. The computer recorded the Landsat spectral response for each group of pixels in each training area. All of the training areas that corresponded to one cover type formed a cell (cluster). Each cell represented a specific location in feature space and could be identified by their spectral coordinates.

Scattergrams, a 2-dimensional representation of spectral coordinates, were used to display cell data in Bands 5 (Y axis) and 7 (X-axis)(Figure 3). During the training procedure, scattergrams were continually examined to ensure sufficient separability between cells. When two or more cover types had similar spectral characteristics, there were usually overlap of cells in Bands 5 and 7 feature space.

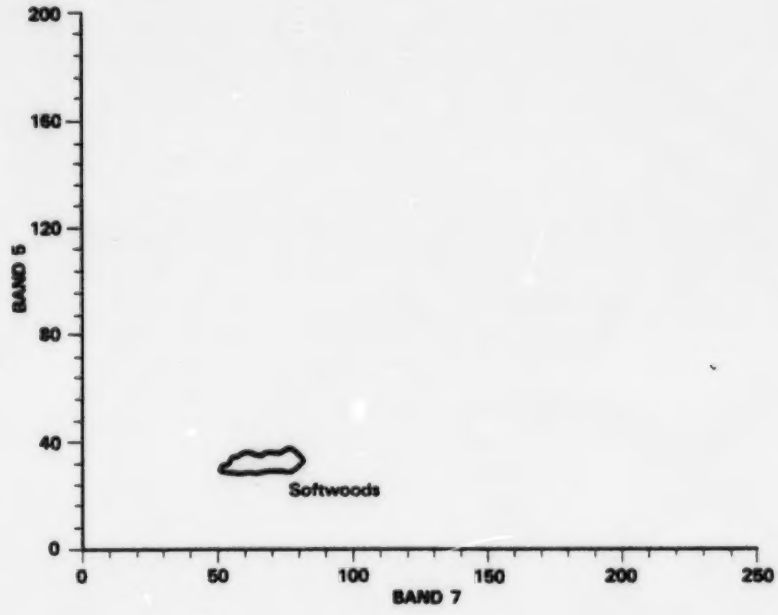


FIGURE: 3: Scattergram showing the location and pattern of spectral cell data for softwoods.

Training areas were compiled in two or three sub-areas where cover types of interest were represented within the study area. When the training process was considered complete, theme statistics were computed. A maximum likelihood signature file was generated using the training area data . The signature file provided the statistical parameters that described the spectral characterization of each cover type.

A maximum likelihood classifier was then applied to the signature file. The classification results were stored in theme files which were displayed on the colour T.V. monitor for a visual assessment. Through the interactive graphics tablet each

theme, with its own colour assignment, could be viewed individually or all at once. Aerial photographs and forest inventory data were used to compare thematic data with known ground cover types. Four or five areas of the image were analyzed in a non-decimated form (i.e. every pixel on every line). The thematic data were checked for classification errors. Thematic patterns were compared to corresponding patterns on the ground reference data. If the results were considered unacceptable further modifications to the training cells were conducted.

A minimum area post-classification filter was applied to the final classification to filter "noise" from the thematic data by replacing small areas with larger surrounding areas.

The filter program was in two stages. The first involved the generation of a map file in which each pixel was assigned a value equal to the size of the (homogeneous) area to which it belonged. In the second stage, those areas of each class that were less than a specified minimum area were replaced by pixels from neighbouring classes.

Confusion matrices were generated by the ARIES-II to evaluate the accuracy of the classification. A program called "Theme Comparison" was used to compare the results of the classification with manually generated check training areas. Check training area files were developed in the same manner as original training area data. Aerial photographs and forest inventory were used to locate and delineate boundaries of each

check training area. A manual theme task was used to generate a theme file from the check training areas. The manual theme file was then compared with the original classification results and the output was in the form of a confusion matrix.

An autocorrelation task was also applied to determine the closeness of correlation of two themes by performing a correlation calculation of their maximum likelihood signatures. The larger the autocorrelation distance (ACD) the more distinct were the two signatures. An identical ACD gave a calculation of zero which meant there was no difference between signatures.

When satisfactory classification results were obtained, the data were reformatted using the Applicon operations software and sent to the Canada Centre for Remote Sensing (CCRS) where colour-coded thematic maps were produced on the Applicon colour plotter.

3.4.2 Digital Enhancements

A digital image enhancement technique was the second remote sensing method examined. The enhancement process consisted of a modified Karhumen-Loeve (K.L.) principle component transform followed by Taylor's (1974) method of colour projection. Two sub-areas of approximately 200,000 pixels each, were chosen within each Landsat DICS scene. Training areas were selected within each sub-area to generate the principle components. The first sub-area represented all major land and water features.

Within this sub-area one general training area included dark areas, water, bogs, and lighter areas. A second training area consisted primarily of upland softwoods. In the second sub-area additional softwood areas were added. Signature files were generated for each of the training areas and then used as input into the modified principle component transform. The result was that each MSS band was converted into components (vector images).

Each component accounted for a portion of the total variance in the original MSS data, but not in equal proportions. The first component accounted for the greatest variance, often in excess of 80-85%. The second and third components account for about 10% and 5%, respectively.

Three components generated from the general training area underwent standard normalization. The general training area also produced two more additional components with a reverse polarization. The softwood training area generated three components that also had standard normalization applied.

Principle component images were mapped into colour space utilizing three visual colour dimensions of brightness, redness - greeness and blueness - yellowness. The brightness axis was produced from the first component of the general training area. The red - green axis was produced from the second component of the general training area in which a reverse polarization was done. The blue - yellow axis was produced from the first component of the softwood training area data.

This process combines the ability of the computer to quantitatively deal with spectral patterns leaving the analyst to evaluate spatial patterns.

4.0 RESULTS

4.1 Digital Classification

An Applicon Inkjet plotter was used to produce colour thematic maps from the themes generated by the maximum likelihood classification (Appendix II). Four sets of maps relating to the four DICS images were created. Ten themes were generated but not all were found on each map sheet. The maps displayed the location of the major vegetation/cover types as defined by Landsat with the corresponding FBP System fuel type identifier. The original mapping scale was to have been 1:250 000 but there was too much information loss, therefore, a larger scale of 1:150 000 was chosen to increase map resolution. This scale also took into account the paper size used with the plotter. Any larger scale would require printing a single map on two sheets of paper.

The confusion matrix was used to assess accuracy of the classification results. The matrix compared pixels of check training areas with the same pixels from the classification. The values off the diagonal in this table indicated a classification error. The matrix did not provide percentages for errors of omission; however, they can be calculated. The theme compare program used to generate the matrix was a quick means of assessing accuracy and helped to determine if there was a problem

originating in the initial training area data. In some instances it was difficult to locate sets of pixels with absolute certainty that provided distinctive spectral signatures for the classes required. Obvious errors in classification were detected by this method (Kalensky 1981).

The Lowland and Precambrian Shield physiographic regions were evaluated individually because of the effect of each region on spectral values and their subsequent affect on classification results.

4.1.1 The Lowland

In the Softwoods theme 59 percent of 9,796 pixels were classified correctly (Table 3). Confusion occurred most often with Jack Pine; however, this was expected due to their spectral similarity.

The Jack Pine theme had only 26 percent of 2,180 pixels correctly classified. Of the 1,609 pixels incorrectly classified, 98 percent (1,570 pixels) were classified as softwoods. This confusion persisted in spite of the extreme care that was taken in choosing check training areas in pure stands (>80%) of Jack Pine.

CLASSIFIED THEME FILE

Manual Theme File	Soft Wood	Jack Pine	Muskeg	Hard Wood	Marsh	Water	Cut Over	Roads	Un Class	Total	%
Soft Wood	5867	3529	301	79	10	0	10	0	0	9796	59
Jack Pine	1570	571	27	6	5	1	0	0	0	2180	26
Muskeg	0	63	1155	0	141	0	0	0	0	1359	84
Hard Wood	3	5	0	762	0	0	0	0	0	770	98
Marsh	0	0	13	0	856	0	0	0	0	869	98
Water	0	0	0	0	0	2841	0	0	0	2841	100
Cut-Over	0	14	5	422	36	0	1344	0	0	1821	73
Roads	4	10	10	2	56	0	0	306	0	388	78

TABLE 3: Lowland region confusion matrix of manually classified pixels in check training areas versus pixels in the classified theme file

The Muskeg theme had 84 percent of 1,359 pixels classified correctly; however, there was some confusion with the marsh class.

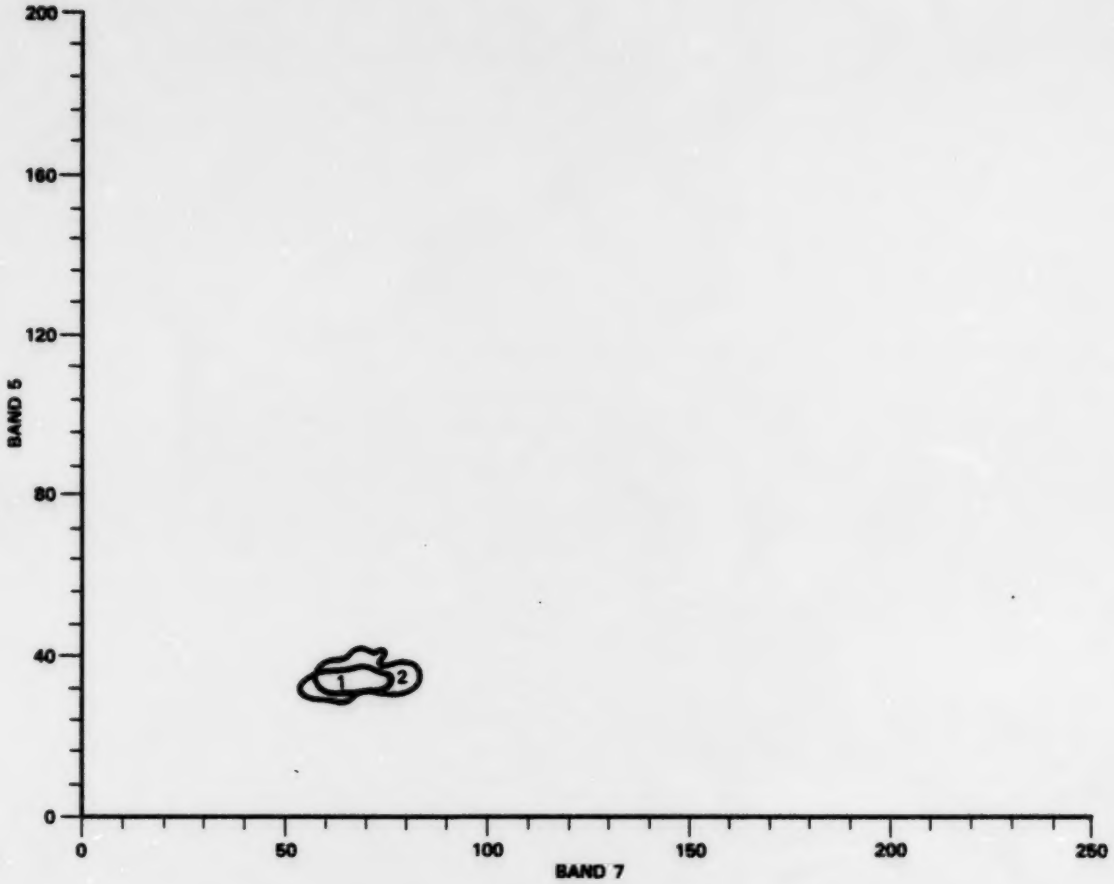
The Deciduous theme had 98 percent of 770 pixels classified correctly. Both themes were very spectrally distinctive.

The Water theme showed 100 percent (2,841 pixels) classified correctly. Check training areas were taken in and around the centre of most lakes, therefore there was little chance of confusion. Most confusion would occur with shoreline pixels which were not considered as important to include for mapping accuracy purposes.

Cutovers were 73 percent correctly classified of 1,821 pixels examined. The majority of confusion occurred with deciduous cover which can be expected because many of the cutovers regenerated back into deciduous and shrub cover.

Cultural features which were mainly roads had 78 percent of 388 pixels correctly classified. There was some confusion between the road and other classes that it came in contact with. Because the narrowness of the road, most of the confusion was with boundary pixels.

In summary, 20,024 pixels were checked in the Lowlands with an overall accuracy of 77 percent with some themes classified more accurately than others. A significant portion of the misclassification resulted from attempting to separate the jack pine from other softwoods. In the scattergram (Figure 4) the spectral similarity between these two themes is evident.



(1) Jack Pine (2) Softwoods

FIGURE 4: Scattergram showing the pattern and location of spectral cells associated with jack pine and other softwoods.

4.1.2 The Precambrian Shield

The difficulty in separating jack pine from other softwoods in the Lowlands resulted in a decision to have one theme for softwoods in the Precambrian Shield region (Table 4).

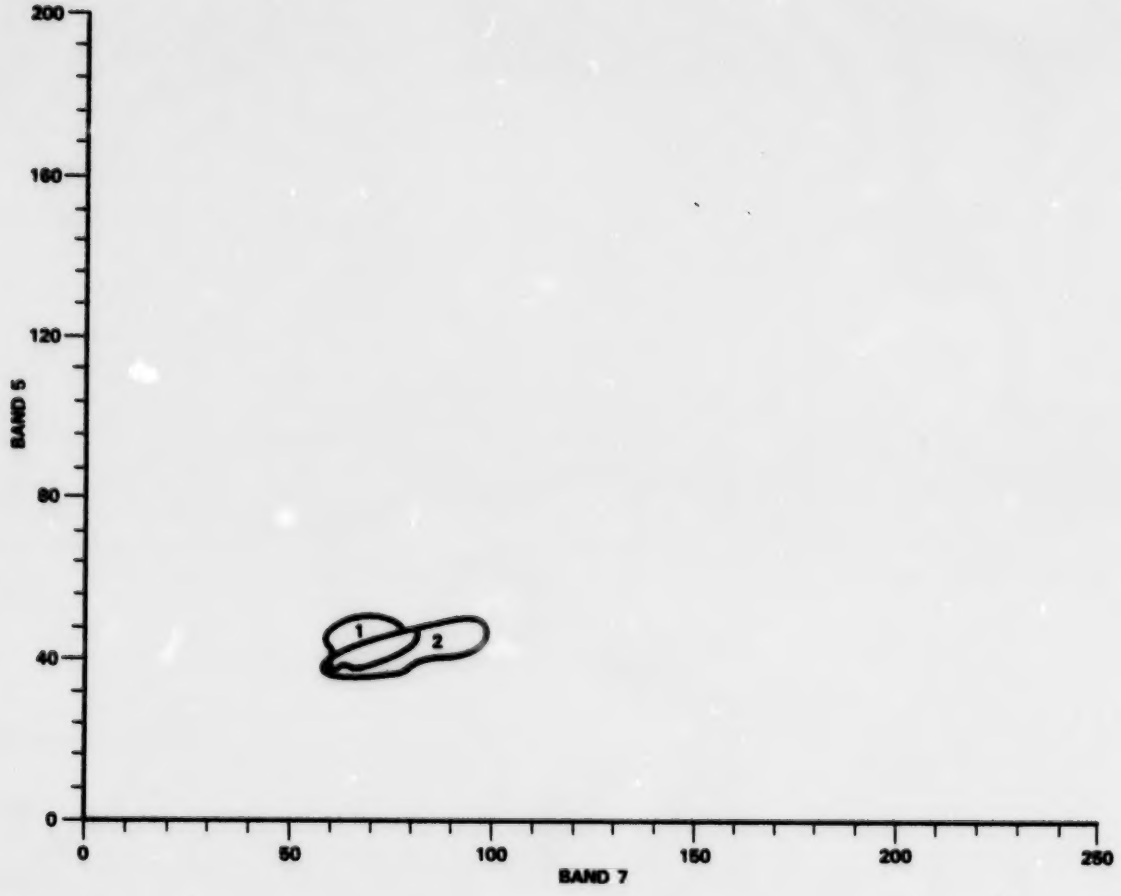
CLASSIFIED THEME FILES

Manual Theme Files	Soft Wood	Muskeg	Hard Wood	Water	Marsh	Treed Rock	Bare Rock	Old Fires	Cut-Over	Roads	Un-Class	Total	%
Soft Wood	5777	1264	30	1	49	21	6	0	0	0	0	7148	80
Muskeg	201	4682	15	1	0	276	75	2	0	0	0	5252	89
Hard Wood	9	10	1540	0	0	0	0	0	0	0	0	1559	98
Water	3	0	0	7123	1	0	0	0	0	0	0	7127	99
Marsh	4	90	0	0	400	185	533	0	72	0	0	1284	31
Treed Rock	28	325	2	0	96	372	228	19	0	0	0	1070	34
Bare Rock	1	9	0	0	29	3	560	35	0	0	0	637	87
Old Fires	91	15	0	0	8	0	0	2005	0	0	0	2119	94
Cut-Over	7	0	0	0	0	0	0	0	506	0	0	513	98
Roads	2	18	1	0	0	0	0	0	0	317	0	338	93

Table 4: Precambrian region confusion maxtrix of manually classified pixels in check training areas versus pixels in the classified theme files.

In the Softwoods theme 80 percent of 7,148 pixels sampled were classified correctly. Some confusion occurred with treed muskeg where the density of tree canopy was greater than or equal to 50 percent. In the Muskeg theme 5,252 pixels were sampled with an 89 percent accuracy. There was some confusion with Softwoods and Treed Rock. The Deciduous theme had a very distinctive spectral signature resulting in 98 percent accuracy. The Water theme had 99 percent of 7,127 pixels sampled correctly. In the Marsh theme 1,284 pixels were sampled. Marsh was only 31 percent correctly classified with confusion between Bare Rock and Treed Rock. Of the 884 pixels incorrectly classified, 60 percent was Bare Rock and 21 percent was treed rock. Both these themes had very similar signatures to marsh.

The ACD between Bare Rock and the Marsh signature file was only 2.122 (Table 5). The Treed Rock theme displayed 34 percent correctly classified of 1,070 pixels. Confusion existed with muskeg and bare rock. The scattergrams indicated significant overlap between treed rock and muskeg (Figure 5). Also, the ACD between these two themes were 0.857 (Table 5) which indicated they were almost the same spectrally. The ACD between Treed Rock and bare rock was 2.431 which indicated a close similarity in spectral signatures.



(1) Treed Rock (2) Muskeg

FIGURE 5: Scattergram showing the pattern and location of spectral cells for treed rock and muskeg.

In the Bare Rock theme, 637 pixels were examined and 87 percent were correctly classified.

In the Wildfire theme 94 percent of 2,119 pixels were classified correctly. Burns (<5 years) were identified, either spectrally or by manual techniques. Where the burn was not spectrally separable its spatial pattern was delineated using the manual theme generation process.

Cutovers were well defined on the Landsat data. Approximately 513 pixels were examined with a 98 percent accuracy. Both spectral and spatial parameters were used to define the cutovers. If the cutover was not spectrally separable the spatial characteristics were used to generate a theme file by means of the manual theme task. In the road theme 338 pixels were examined with a 93 percent accuracy. Many of the roads were generated using the manual theme task.

In summary, 27,047 pixels were checked with an overall accuracy of 80 percent. There was difficulty separating treed rock from muskeg and there was confusion between bare rock and marsh.

The use of the recent Landsat imagery provided updated information on cutovers, old fires and new roads all of which are important information for suppression planning.

Table 5

AUTOCORRELATION DISTANCES BETWEEN MAXIMUM LIKELIHOOD SIGNATURES FOR PRECAMBRIAN SHIELD REGION

	Softwood	Muskeg	Hardwood	Water	Marsh	Treed Rock	Bare Rock
Softwood	0.000	5.225	9.805	26.517	5.524	5.890	5.645
Muskeg	5.225	0.000	10.114	32.131	6.076	0.857	3.579
Hardwood	9.805	10.114	0.000	46.648	20.438	12.212	12.948
Water	26.517	32.131	46.648	0.000	10.702	53.786	17.739
Marsh	5.524	6.076	20.438	10.702	0.000	4.187	2.122
Treed Rock	5.890	0.857	12.212	53.786	4.187	0.000	2.431
Bare Rock	5.645	3.579	12.948	17.739	2.122	2.431	0.000

4.2 Digital Image Enhancements

Output data resembled colour aerial photography, and were produced at approximately 1:150 000 scale. The technique comprised of using principle components and an enhancement process developed by fire management systems project staff at the Petawawa National Forestry Institute (PNFI). Deep blues represented pure stands of softwood, pale greens depicted hardwood. Enhancements were compared to thematic maps and agreement between the two sets of data was evident, however, no quantitative assessment was conducted. On the enhancements, bogs, cutovers, treed rock and clouds were similar in colour.

Interpretive skills, and other data sources were required to determine the difference between these cover types. This was a significant factor for fire managers for they were unable to differentiate between many fuel types. There also was no legend to assist the user in determining what colour represented what fuel type. Enhancement cover type boundaries appeared more precise than the irregular boundaries of thematic maps, however, this was not considered important when mapping at 1:150 000.

Output products were very difficult to obtain. Two enhancements were generated at the PNFI using their DICOMED Image Recorder.

Dipix Systems Ltd. are the only agency that could provide the enhancement products required for an operational program.

The cost would be 165 dollars per enhancement. This is approximately four times the cost of a one Applicon plot for an area of similar size. Clearly, the operational use of enhancements by fire management personnel will only be achieved after a period of training on how to interpret the data and the cost is more in line with other output data.

5.0 CONCLUSIONS

Landsat digital data can be used for fuel type mapping. It is recognized that there are other factors that effect fire behaviour i.e., topography and weather. These factors combined with the fuel type maps will provide the fire manager with increased information for determining potential fire behavior.

The overall accuracy for the fuel types on the Manitoba Lowlands was 70 percent with the majority of the inaccuracy attributed to difficulties in separating jack pine from other softwoods.

On the east side of Lake Winnipeg where jack pine is a dominant species, Pokrant and Wilson (1984) were successful in discriminating between pine and other softwoods, using single-date Landsat MSS data. The physical and biological factors for the east-side of Lake Winnipeg are different from those of the study area. It appears that site factors will have an overriding effect on the success of separating pine from other softwoods on single-date Landsat MSS data. This problem could be considered a limitation in the use of satellite data for fuel type mapping; however, the knowledge of the location of high risk areas in general is very important in fire management operations. Had the difficulty in discrimination been between jack pine and muskeg, the problem would have been considered critical. Also, it is possible that by using Landsat multi-temporal data or Thematic mapper data this problem could be alleviated. On the Precambrian Shield the softwoods were combined resulting in an overall accuracy of 80 percent for the region.

The Fire Management and Communication Section can see the use of both thematic maps and digital enhancements for wildfire planning purposes. Thematic maps which present a synoptic view of fuel types will be used in regional offices where the deployment of fire suppression resources are planned and

coordinated. Furthermore, they will be of use in the planning of fire suppression strategies on large fires. The value of digital enhancements will also be realized in developing suppression tactics on large individual fires. The enhancement which retains and amplifies detail of the original satellite data will also be of use in the field for such things as prioritizing initial attack, locating water sources and selecting access routes for field crews.

Fire management personnel appreciate the need for training staff in the interpretation and application of these new products. In cooperation with the Manitoba Remote Sensing Centre, training will be provided to regional managers and field staff so as to enable them to properly interpret the data and to fully understand their significance in evaluating fire behavior.

Fire Management and Communications Section has planned to integrate the study results into the fire management program for the 1984 fire season and to expand Landsat fuel type mapping to other areas of the province. The area east of Lake Winnipeg from the 53rd parallel to the Manitoba-Minnesota border is scheduled for mapping in 1984/85 with subsequent mapping for the rest of the forested zone to follow.

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A P P E N D I X I

Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING

Between

The Department of Natural Resources
of the Government of Manitoba

and

The Department of Energy, Mines and Resources
of the Government of Canada

for

COOPERATION IN REMOTE SENSING

ARTICLE I. Scope and Objectives

The Department of Natural Resources of the Government of Manitoba (hereinafter referred to as DNR) and the Department of Energy, Mines and Resources, Government of Canada (hereinafter referred to as EMR) hereby state their intention to pursue scientific and technical cooperation in remote sensing in accordance with this Memorandum of Understanding (hereinafter referred to as "Memorandum") which establishes the procedure for cooperation.

The purpose of this Memorandum is to establish a framework for enhancing the scientific and technical capabilities of the Government of Manitoba in the application of remote sensing technology to natural resource management activities. EMR and DNR (hereinafter referred to as Parties) will undertake to implement a joint technology enhancement program as described in Schedule A. It is understood that EMR may include the cooperation of personnel from other federal government departments to provide specific scientific and technical capabilities pertinent to the projects being undertaken in the program.

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ARTICLE II. Responsibility of the Parties

EMR will use its best efforts to: (i) have available for consultation a remote sensing specialist during the term of this Memorandum to assist provincial personnel engaged in demonstration projects; and (ii) provide training to provincial personnel in the use of the image analysis system lent to DNR. In addition, EMR will use its best efforts to give priority consideration for the use of image analysis facilities and remote sensing aircraft of the Canada Centre for Remote Sensing during the term of this Memorandum for the purposes of this cooperative endeavour.

DNR will endeavour to: (i) provide office accommodation for federal personnel engaged in the program; (ii) schedule, operate and maintain the image analysis system in accordance with the loan agreement, and (iii) coordinate the activities of provincial agencies involved in the demonstration projects.

The Parties will jointly define the objectives, resource requirements, and criteria for evaluation of specific demonstration projects. Changes to project design or the initiation of new projects will be undertaken only after consultation between designated representatives mutually acceptable by the Parties. Responsibilities of the Parties are detailed in Schedule A.

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ARTICLE III. Source of Funding

Cooperative activities under this Memorandum will be subject to, and dependent upon, the financial support and manpower available to the Parties. Each Party will pay all operating expenses of its employees engaged in the program. DNR will use its best efforts to acquire satellite and airborne remote sensing imagery required for the projects, from Canada in accordance with its standard rates and to provide office accommodation for the program in Winnipeg.

ARTICLE IV. Review of Activities

The technology enhancement program established by this Memorandum will be monitored and evaluated by interdepartmental committees at the federal and provincial level. A federal Technology Enhancement Review Board, chaired by EMR, includes representatives of Agriculture Canada and Environment Canada. A provincial Advisory Committee, consisting of directors of the branches of provincial departments involved in the demonstration projects, will make recommendations to DNR on the nature of a provincial follow-on program when this Memorandum expires.

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ARTICLE V. Entry into Force and Termination

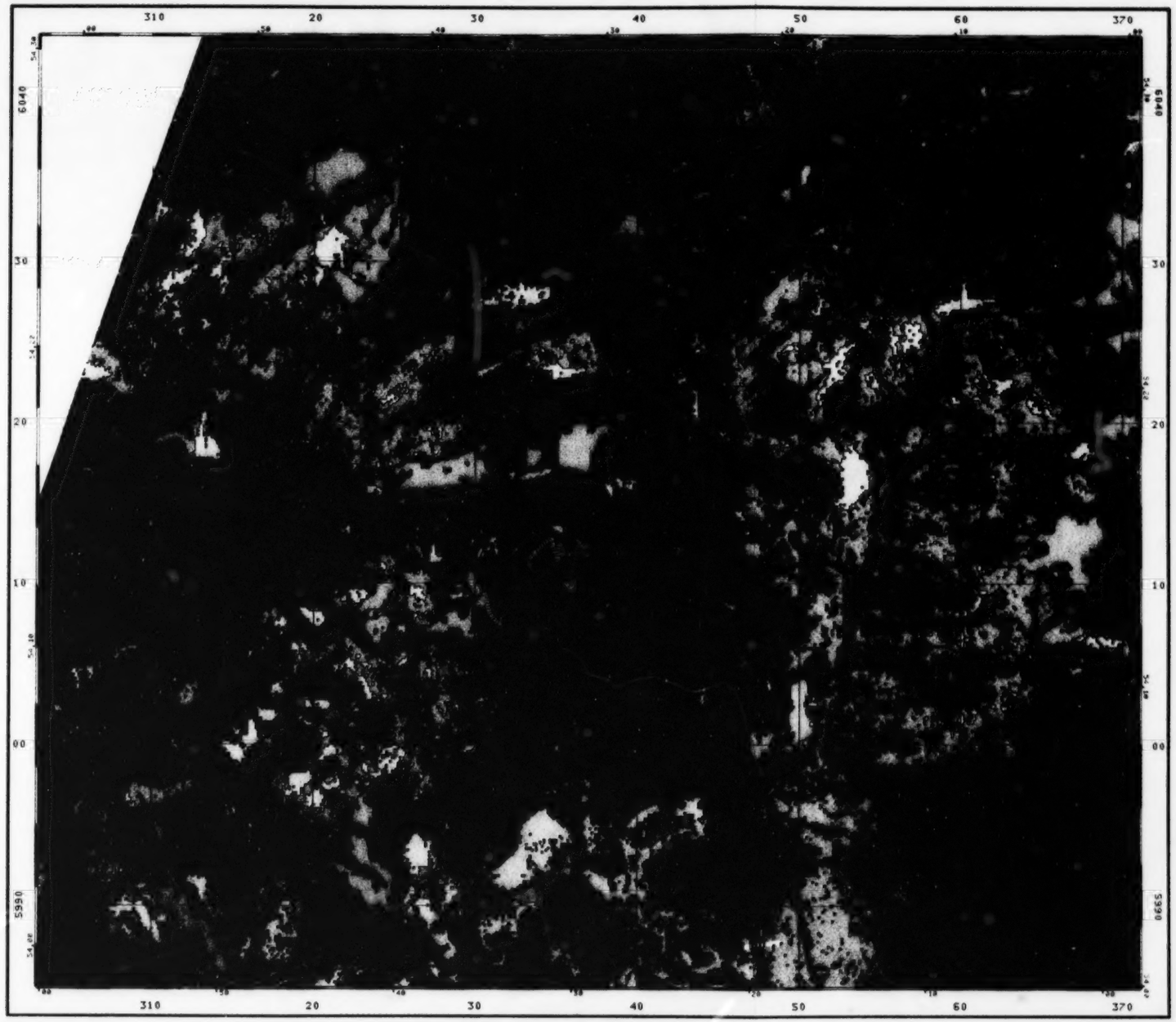
This Memorandum shall enter into force upon signature by both Parties and remain in force until March 31, 1984. The term of the Memorandum may be extended upon written and mutual agreement by the Parties.

Done at Ottawa, Ontario this day of November 17th 1982.

Done at Winnipeg this day of November 9th 1982.

A P P E N D I X II

Thematic Map Example for the Fuel Type Mapping Project



FOREST FUEL TYPE MAP

FIRE MANAGEMENT SECTION
PRODUCED BY MANITOBA REMOTE SENSING CENTRE
N.T.S. 63K/SW ROCKY LAKE REGION

SOFTWOODS (FBP: C-2)
52.212 HECTARES

PINE (FBP: C-3)
69.553 HECTARES

MUSKEG
65.959 HECTARES

HARDWOODS (FBP: D-2)
61.575 HECTARES

MARSH (FBP: O-1)
27.228 HECTARES

CUTOVERS (FBP: S-1)
11.814 HECTARES

CULTURAL
1.393 HECTARES

MULTICLASSIFIED

UNCLASSIFIED